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MULTILIN

GE Power Management

Distance Relays Fundamentals

DISTANCE RELAYS FUNDAMENTALS

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INTRODUCTION

Distance functions have been in use for many years and have progressed from the original electro-mechanical types through analog types and now up to digital types of functions. The purpose of this paper is to discuss fundamental features of the three types of functions and possible problems that may be encountered in their design and application.

MHO FUNCTIONS

SIMPLE MHO FUNCTION

A simple mho distance function, with a reach of Z ohms, is shown in Figure 1. This diagram is exactly equal to an R-X diagram except that all of the impedance vectors have been operated on by the current I. The mho function uses the current and voltage measured at the relay to determine if the apparent impedance plots within the mho characteristic. The determination is made by comparing the angle between the operating quantity (IZ – V) and the polarizing quantity (V, where V = IZf). If the angle is less than or equal to 90°, then the fault impedance Zf plots within the characteristic, and the function will produce an output. If the angle is greater than 90°, then Zf falls outside of the characteristic and no output will be produced. Assume that the angle of maximum reach (θ) and the angle of ZL (ϕ) are equal. On that basis, the conditions shown in Figure 2 will be obtained. The key point to note in this phasor analysis (a convenient way to view relay performance) is the magnitude of the IZ – V (Vop) phasor and its relationship to the V (Vpol) phasor. Operation will occur whenever Vop and Vpol phasors are within 90° of each other and provided both Vop and Vpol are greater than the minimum values established by the sensitivity of the relay design. For the balance point fault, IZ-V is zero, therefore no operation occurs, which is expected. For an internal fault, IZ – V and V are in phase, therefore the function operates as expected. For the external fault, operation does not occur because IZ V and V are 180° out of phase. Observe that for the balance point fault, the V is exactly equal to IZ. This is true for the three-phase fault shown (also for a phase-to-phase fault) and for a phase distance function only. For a ground distance function, this will only be true if the function includes zero sequence current compensation as discussed later in this paper.

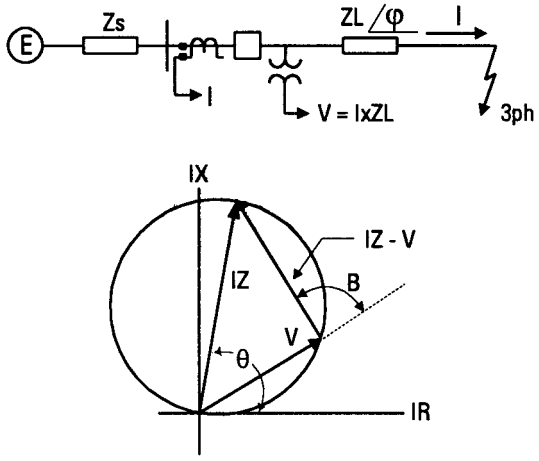
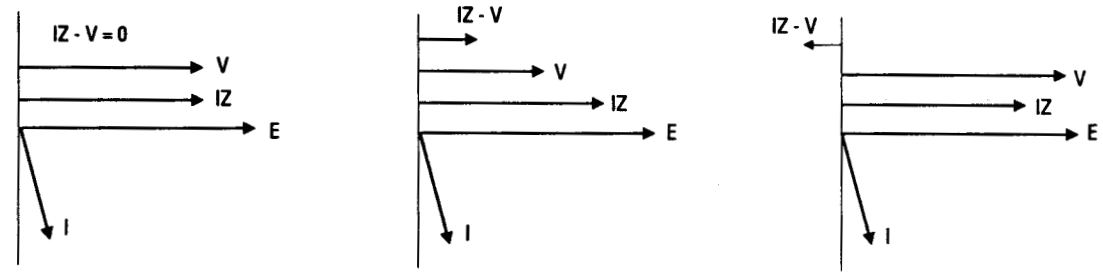


Figure 1 - Simple Mho Function



a. Balance Point Fault, V = IZ b. Internal Fault, V < IZ c. External Fault, V > IZ

Figure 2 - Phasor Analysis of Operation of Simple Mho Function

The polarizing quantity for this simple mho distance function is simply equal to the fault voltage V, therefore the function is said to be self-polarized and has the simple characteristic shown in Figure 1. In general, a voltage different than the fault voltage is used to polarize the function and this will have an effect on the characteristic.

POLARIZING QUANTITY

A number of polarizing quantities have been used in developing phase and ground mho distance functions. Following are some of the more commonly used:

- Self-polarized (Va for Phase A function, Vab for the Phase AB function, etc.)
- Positive Sequence Voltage (Va1 for Phase A function, Vab1 for Phase AB function, etc.)
- Quadrature Voltage (Vbc shifted leading 90° for Phase A function)
- Median (midpoint of Vbc to Va for Phase A function)
- Leading phase (Vc shifted leading 240° for Phase A function)

An mho function that is other than self-polarized is often described as being cross-polarized. No attempt will be made here to describe the effect of all types of cross-polarization. Suffice it to say that cross-polarization will still result in a circular characteristic, but one that may also swivel and vary in size dependent on system conditions.

For example, consider the case of a distance function that uses positive sequence voltage as the polarizing signal. The characteristics for a phase distance function and a ground distance function that use positive sequence voltage polarization are shown in Figure 3 (1) and are drawn for a phase-to-phase and phase-to-ground fault respectively. As can be seen, these characteristics are not fixed in size, but will vary proportionately with the source impedance directly behind the function. Load flow[1] will cause the characteristic to swivel to the left (as shown) or to the right relative to the forward reach (point a), with the amount and direction of the swivel depending on the magnitude and the direction of load flow. The effect of the swivel and variability is to accommodate more resistance in the fault (to be discussed later) than would be obtained with a self-polarized mho function. Note that the plots of Figure 3 are for faults in the forward (tripping) direction. The function will not operate for an inductive fault behind them.

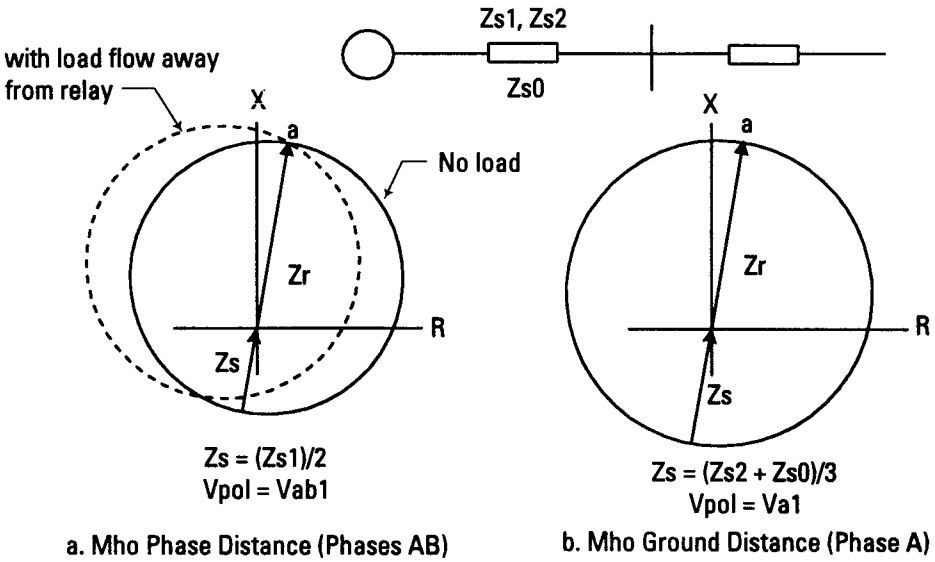


Figure 3 - Variable Mho Characteristic (positive sequence voltage polarized)

All mho distance functions require voltage in order to operate. For a fault right at the relay location, the voltage will be very small (approaching zero for a bolted fault), and a self-polarized mho function may not operate for such a fault, whereas a cross-polarized function will, except for a three-phase fault For a three-phase close-in fault, all three voltages will be very small, therefore operation of any of the cross-polarized functions will be jeopardized because there will be very little, or no voltage available to develop the polarizing quantity. To overcome this deficiency, memory is added to the polarizing circuits.

MEMORY ACTION

In electro-mechanical and analog type mho functions, memory is accomplished through the use of tuned filter circuits. The circuits are tuned to the power system frequency and in effect remember the voltage seen by the function prior to the fault. The filters are designed with a factor sufficient to allow mho function operation until the memory dies away; i.e., during the filter ring-down period. Typical filter outputs lasts in the order of three to five cycles of power system frequency, which is sufficiently long to allow the function to produce an output and so initiate zone 1 direct tripping or high speed pilot tripping. Time-delayed backup tripping could not be counted on for close-in faults however, because the filter ring-down time is generally not long enough to allow the backup timers to time out.

Memory in digitally implemented mho functions is accomplished using digital techniques, consequently there is no ring-down as with analog filters, and the remembered voltage can be held for any desired period of time. If the remembered time is set long enough, then time-delayed backup tripping can also be initiated for close-in faults. In general, It is best to allow the voltage applied to a mho function to adapt to the system voltage as soon as possible following a system disturbance so that the function is in step with the system when the disturbance is cleared. For example, consider a fault of sufficient duration so that the voltage at the relay may have shifted considerably as the

result of a system swing caused by the fault. If the memory is set long enough such that the function is still sensing the voltage prior to the disturbance when the disturbance is cleared, then problems may be introduced. To avoid any possible problems, memory time should be kept to a minimum, or an adaptive memory can be used. An adaptive memory can be implemented by sensing the voltage at the time of the fault. If the voltage is less than a set value (10 percent for example) then the voltage prior to the fault will be remembered and used by the function until the fault is cleared as indicated by reset of the function. On the other hand, if the voltage is greater than the set value, then the voltage prior to the fault will be remembered for a short period of time (5 cycles for example) after which the voltage applied to the function will adapt to the actual voltage. In this way, time-delayed backup protection can be implemented for close-in faults while allowing the function to change to the system voltage with minimum time delay for all other faults.

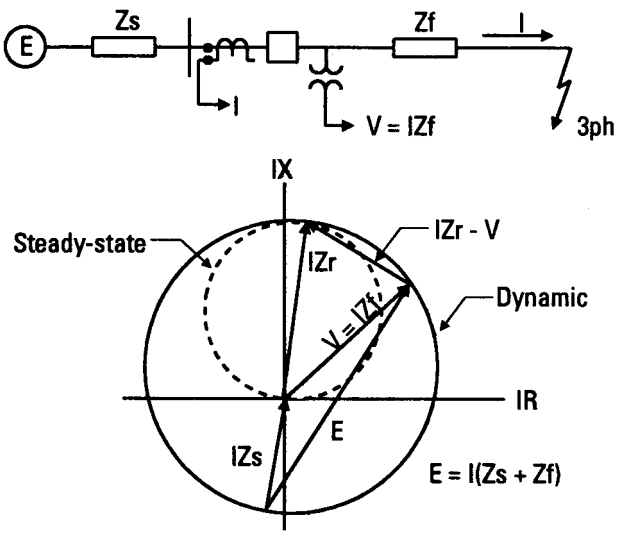


Figure 4 - Dynamic Response

The result of memory action is to produce a dynamic (time varying) response from the function that is different from the steady-state response. This results in the dynamic and steady-state characteristics shown in Figure 4 (remember that this diagram is the same as an R-X diagram except for the inclusion of the current 1). This difference in response comes about because the function is using a different polarizing voltage during the memory period as opposed to that used steady-state. The dynamic characteristic lasts as long as the memory time. If the memory changes with time, as would happen with an analog filter, then the dynamic characteristic changes in time as the remembered voltage changes to the steady-state value. In terms of Figure 4, the function produces the dynamic characteristic using the remembered voltage, E, and then changes to the actual voltage, V to produce the steady-state characteristic. The function in Figure 4 would theoretically operate dynamically because the fault impedance (Zf) just falls on the characteristic, but it would not operate steady-state because Zf falls outside of the steady-state characteristic.

POLARIZING VOLTAGE SENSITIVITY

All distance functions require a finite amount of voltage in order to operate. Exactly how much is required is a measure of the sensitivity of the function and is determined by the type and design of the function.

The voltage polarizing sensitivity is set by design and if the voltage at the relay falls below that level then the function will not produce an output except by memory action. If there is no memory, then there will be no output. If the memory is finite in duration, then the output will last just as long as the memory. If adaptive memory is used, then the output will last until the function resets following clearing of the disturbance that initiated operation of the function.

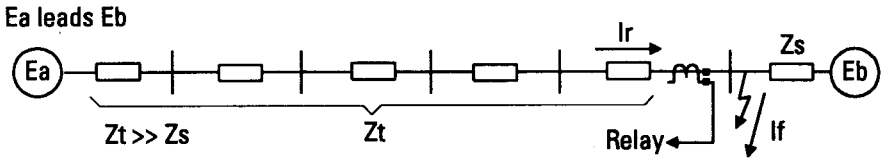


Figure 5 - Fault Behind Mho Function

It is possible to design the relay input circuits to sense very low magnitudes of voltage: however, there are good reasons for placing sensitivity limits on the voltage polarizing circuits, the primary purpose being to prevent operation for a fault directly behind the function[2]. Consider the system shown in Figure 5. For a three-phase fault at the location shown, resistance in the arc produces a voltage at the relay that is generally accepted to be approximately 5 percent or less of the power system voltage[3][4]. The effect of load flow is to cause a shift in this voltage relative to the relay current because the relay current (Ir) and the total fault current (If) are out of phase with each other. The shift in phase in the voltage is more pronounced as the impedance, Zt, gets larger relative to the impedance, Zs.

A relay that operates on the quantities given in Figure 1, can be easily analyzed for the conditions of Figure 5 by using phasors as shown in Figure 6. The function will not operate dynamically because the angle (A) between Vop and the initial polarizing signal (voltage at relay prior to the fault) is much greater than 90 degrees. If the sensitivity of the voltage polarizing circuit is less than the arc drop, then the mho function will operate steady-state for the conditions shown because the angle (B) between the operating signal, Vop, and the final polarizing signal, Varc, is less than 90 degrees. If the sensitivity of the polarizing circuit is greater than the arc drop, then steady-state operation will not occur regardless of the angle. This analysis is predicated on the memory changing from the prefault voltage to the fault voltage during some finite time period. If the fault is cleared before the memory expires, then operation will be prevented. If the memory voltage is held fixed at the prefault value, then operation for this condition will also be avoided. Note that this analysis applies for any function, self-polarized or cross-polarized for any three-phase fault, because the only voltage left to create the polarizing quantity is the arc voltage itself. For phase-to-phase, or phase-to-ground faults (assuming arc resistance only in the fault), a cross-polarized function will perform properly because the unfaulted phase voltages will be available to create a polarizing signal that will not be shifted as much in value as is the arc voltage.

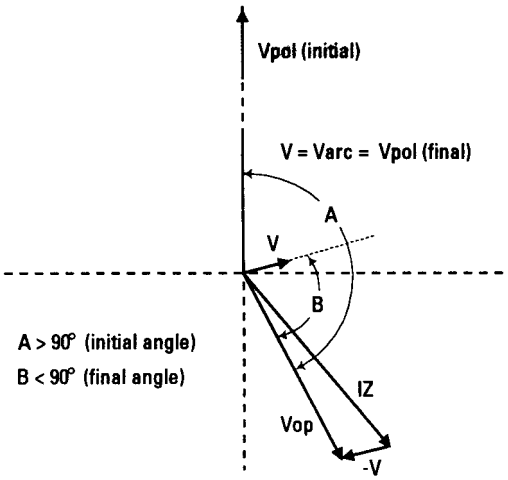


Figure 6 - Phasor Analysis of Mho

CURRENT SENSITIVITY

In addition to requiring a finite amount of voltage to operate, a mho distance function also requires a finite amount of current The amount of current required is fixed by the design of the function and is related to the reach set on the function. For any given reach setting, the function will produce the set reach only for currents above a certain level. If the current is reduced below that level, then the function will start to pull back in reach until a current level is reached at which operation of the function will stop. For example, consider an electro-mechanical mho distance function in which torque must be produced to cause rotation of the element. The torque must be sufficient to overcome the inertia of the element plus the restraining spring that is used to hold the contacts open when no electrical restraining torque is being produced. Sensitivity of an electro-mechanical mho function could be found by examining the so-called bullet curve, an example of which is shown in Figure 7. From this curve, it can be seen that the amount af current required to operate the function is related to the basic ohmic reach of the function; i.e., the higher the basic reach that is selected, the lesser the amount of current required to produce operation. It is for this reason that the instruction books always recommend that the highest basic ohmic reach be used if the desired reach can be obtained through the use of any of the available basic ohmic reaches. For a 3 ohm basic reach setting, the function requires at least 1.5 amperes of current to produce operation. Note however, that the function will reach to only about 80 percent of the set reach at 1.5 amperes and that it takes about 5.0 amperes of current before the full reach will be obtained. The area between 1.5 amperes and approximately 5 amperes is referred to as the region of "pull back" because the full reach of the function is not obtained in this area. The lower portion of the curve shows the area of dynamic operation of the mho function.

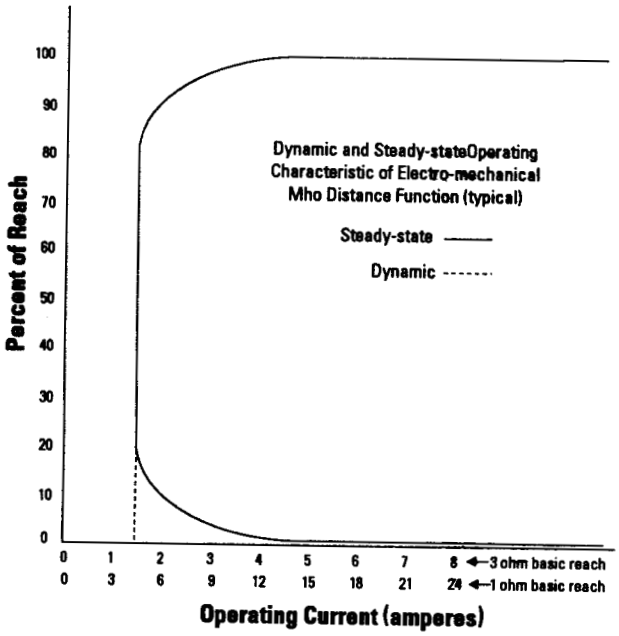


Figure 7 - Typical Bullet Curve

Solid state and digital type mho functions do not require torque to operate and have no restraining springs to overcome. However, signal levels must be established below which the functions will not be allowed to operate. This is required to overcome errors and thresholds that are indigenous to any type of electronic equipment and design (analog or digital). Sensitivity of these types of functions can be determined from curves or through equations provided by the maker of the equipment For example, the sensitivity of one type of phase distance function can be calculated as follows:

$$I\phi\phi = \frac{K}{Zr \times (1 - X)}$$

Where,

$I\phi\phi$ = phase-to-phase current required to produce the *actual reach*

Zr = reach setting

X = *actual reach*/reach setting

K = design constant

The *actual reach* referred to is the reach that will be obtained at the calculated current level ($I\phi\phi$), taking into account any pull back. If, for example, it is desired to know the current that is required to assure that the function will reach at least 90 percent of the set reach, then X should be set equal to 0.9. Note that the current required to produce a given reach is inversely proportional to the reach setting. Longer reach settings require less current and vice versa. Functions with extremely short reaches may require a significant amount of current to produce operation and may not operate under all conditions.

ARC/FAULT RESISTANCE

For a multi-phase fault, an arc is established between the phases that results in a nearly constant voltage drop across the arc that as noted earlier is approximately equal to 4 to 5 percent of the driving system voltage. The arc appears to be purely resistive in nature and because of the constant voltage drop, the resistance varies inversely with the total current flowing in the arc. This is not strictly true for single-line-to-ground faults, wherein there may be an additional drop that is introduced through tower footing resistance, etc. If a midspan-to-ground fault occurs through a tree or fire, for example, then there could be a significant resistive component in the fault. This resistive component does not vary inversely with the current, as does the resistance in an arc, therefore, there could be a significant voltage drop across it. In any event, although the impedance of the fault is considered to be purely resistive, that does not mean that it will appear to be so to a distance function. The effect of load flow and/or non-homogeneity (system impedance angle are different) must be taken into account. This is illustrated in Figure 8.

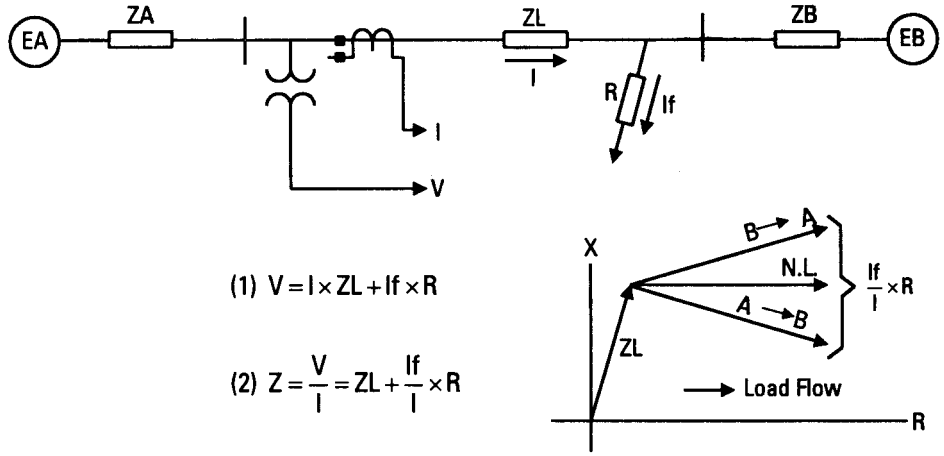


Figure 8 - Effect of Load Flow Figure or Non-homogeneity on Arc/fault Resistance

As can be seen in Figure 8, the effect of load is to shift the resistance so that it appears to have a reactive component. The direction of the shift and the amount of shift depends on the direction and the magnitude of the load flow. System non-homogeneity has a similar effect but not nearly as severe as that caused by heavy load flow.

For a *multi-phase fault*, the resistance varies inversely with the current because the voltage drop across the arc is constant in magnitude. As a consequence, the system source-to-line impedance ratio becomes important in the case of multi-phase faults. As the source to line ratio increases, the voltage drop in the arc appears larger relative to the voltage drop in the line itself. The effect is to make the resistance appear to be larger relative to the line impedance as shown in Figure 9. On lines with low source-to-line ratios (typically long lines), the resistive component of the impedance seen by a distance function is very small and may be considered negligible. On the other hand, as the source-to-line ratio increases (typically short lines) the resistive component of the apparent impedance seen by the function can be quite large and can no longer be considered negligible. If the distance function is cross-polarized, then the effect of the crosspolarization will cause the characteristic to swivel in the same direction as the arc resistance itself (see Figure 3), and so preclude operation.

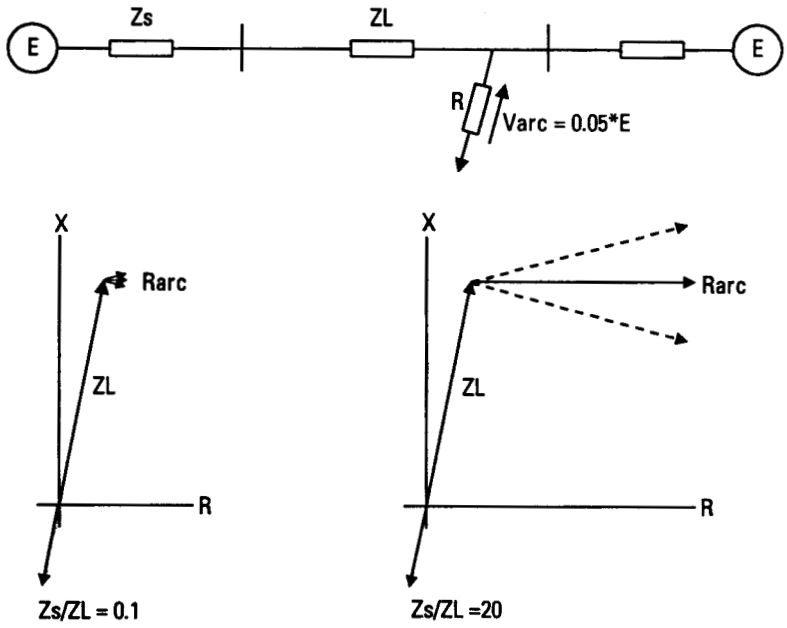


Figure 9 - Effect of Source-to Line (Zs/ZL) Ratio

Infeed affects single-line-to-ground faults similarly, but because the resistance in the fault is linear, the effect can be much more dramatic. The effect of the infeed is to cause the voltage to be magnified in value so that the resistance can appear much larger than it actually is. In this case, the resistance may be so large as to render ground distance functions ineffective. For example, if the relay current, I, in Figure 8 is 1 ampere and if the fault current, If, is 10 amperes, then from equation 2 of the Figure:

$$Z = ZL + \frac{If}{I} \times R = ZL + 10R$$

As far as any distance function at the left is concerned, the fault resistance (for a ground fault with linear resistance) appears to be 10 times as large as it actually is thus increasing the chance that the function may not operate. If the fault is cleared at the right terminal, then the distance function at the left will see the true resistance at that time (If = I) and the function may operate (but not necessarily). At the right terminal of the line the effect will not be as large, and depending on the magnitude of the resistance, a ground distance function located there may or may not operate. If the ground distance function at the right does not operate because the resistance is too large, then the fault cannot be cleared by distance relays, and ground directional overcurrent relays (or a scheme employing current alone) will have to be employed to insure clearing for high resistance ground faults.

REPLICA IMPEDANCE

Many solid state relay systems (and some electro-mechanical relays) use a magnetic circuit such as a transactor to develop the transmission line replica impedance. A transactor is an iron core reactor with an air gap, and it produces an output voltage that is proportional to the input current. The transfer impedance of the transactor is used to define the reach, Z, and the angle of maximum reach, θ of the mho distance function shown in Figure 1. The transactor removes the DC component from the current signal. Digital relays may use a so-called "software implementation" of a transactor, rather than a physical transactor, to create the replica impedance. In this way, the dc component can be removed from the current derived signal that is used in a digital relay.

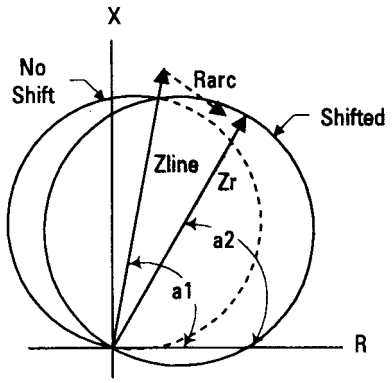


Figure 10 - Phase Shifted Function

In setting mho distance functions, it is desirable to match the replica impedance angle to the line impedance angle as closely as possible. In this way, the function will replicate the line voltage which will lead to an accurate measurement being made. If the replica impedance is set at an angle other than the line angle, then replication of the line voltage will be obtained only if there is no dc offset in the current. Any dc offset in the fault current will produce an error in the replicated voltage until the dc offset subsides. The error will be in the direction to promote overreaching if the angle is made lower than the line angle. Of more concern when an angle other than the line angle is used is demonstrated in Figure 10. In this application, the zone 1 function which is typically set to reach 90 percent of the line impedance, has been tipped away from the line in an attempt to obtain greater coverage for arc resistance while still maintaining a reach of 90 percent along the line angle. Greater arc resistance coverage has been obtained, but at the cost of possible overreaching for a fault at the end of the line with fault/arc resistance as shown in the figure. While not shown, the dynamic response and the variable response of a cross-polarized mho function will exacerbate the problem because the characteristic will be expanded beyond that shown in the figure.

ZERO SEQUENCE CURRENT COMPENSATION

It was shown earlier for a fault at the balance point that the voltage developed in the relay would be equal to the voltage drop across along the line for multi-phase faults. This will not be true for a ground distance function during a ground fault if that function uses only the faulted phase voltage V, the faulted phase current 1, and a reach setting that is based only on the positive sequence impedance (ZL1) of the line. For a Phase A to ground fault at the location shown on the system of Figure 1, the sequence networks are connected as shown in Figure 11. The voltage at the relay (Va) can be calculated as follows:

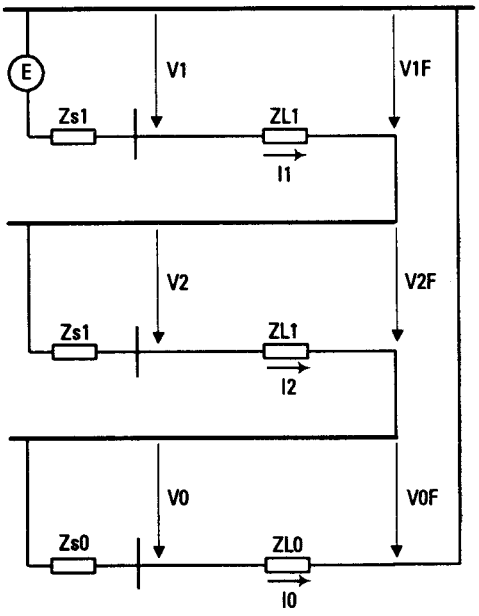


Figure 11 - Sequence Network Connections for SLG-Fault

$$Va = V1 + V2 + V0$$

Where,

$$V1 = I1 \times ZL1 + V1F$$
$$V2 = I2 \times ZL1 + V2F$$
$$V0 = I0 \times ZL0 + V0F$$

Therefore,

$$Va = I1 \times ZL1 + I2 \times ZL1 + I0 \times ZL0 + (V1F + V2F + V0F)$$

But,

$$(V1F + V2F + V0F) = 0$$

Therefore,

$$Va = (I1 + I2) \times ZL1 + I0 \times ZL0$$

The voltage at the relay, Va, is not simply made up of the drop in the positive sequence impedance of the line as for a three-phase fault, but it also includes a factor that is proportional to the zero sequence impedance of the line and the zero sequence current seen by the relay. If a ground distance relay just uses the current Ia and is set with a replica impedance (ZR) that is equal to the positive sequence impedance (ZL1) of the line, then the IZ quantity would be as follows:

$$Ia = I1 + I2 + I0$$
$$IZ = Ia \times ZR = (I1 + I2) \times ZL1 + I0 \times ZL1$$

Note that the IZ quantity is not equal to Va because of the difference between the positive sequence impedance and the zero sequence impedance of the line. The IZ quantity can be made equal to Va by multiplying the zero sequence current by the ratio of the zero sequence impedance to the positive sequence impedance (ZL0/ZL1) of the line. If this ratio is called K0, then a compensated current (Iac) results:

$$Iac = I1 + I2 + K0 \times I0$$

The IZ quantity then becomes:

$$IZ = Iac \times ZL1 = (I1 + I2) \times ZLI + K0 \times I0 \times ZL1$$
$$IZ = (I1 + I2) \times ZL1 + I0 \times ZL0$$

From this, the operating quantity, Vop, can be calculated:

$$Vop = IZ - Va = \{(I1+I2) \times ZL1 + I0 \times ZL0\} - Va = \{(I1+I2) + I0 \times ZL0\} - (I1+I2) + I0 \times ZL0 = 0$$

IZ is now exactly equal to Va and the operating quantity IZ-V is therefore equal to zero just as was the case for the three-phase fault described earlier. K0 is referred to as the zero sequence current compensation factor and it is used to match the zero sequence impedance of the line. The ratio of the voltage Va to the compensated current Iac, now yields:

$$\frac{Va}{Iac} = \frac{(I1 + I2) \times ZL1 + I0 \times ZL0}{I1 + I2 + K0 \times I0} = \frac{ZL1\{I1 + I2 + (ZL0 / ZL1) \times I0\}}{\{I1 + I2 + (ZL0 / ZLI) \times I0\}} = ZL1$$

The effect of using K0 therefore, is to allow the function to measure impedance in terms of the positive sequence of the line, which in turn allows the user to set the function in terms of the positive sequence impedance of the line.

Depending on the relay, the K0 factor may also be expressed as follows:

$$K0 = \frac{Z0L - Z1L}{K \times Z0L}$$

Where, K can be 1 or 3 as determined by the relay design

Regardless of how K0 is defined, the effect on performance is the same as described above.

OPERATION OF GROUND DISTANCE FUNCTIONS FOR REVERSE DOUBLE-LINE-TO-GROUND FAULTS

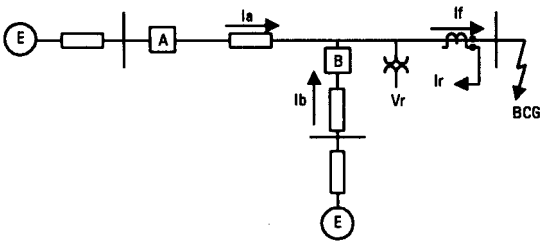


Figure 12 - BCG Fault Behind Function

As was just shown, zero sequence current compensation facilitates application of ground distance functions, but it, along with the relay reach, may also lead to an operational problem with the ground distance function associated with the unfaulted phase during a double-line-to-ground fault behind the function (the Phase A function for a BCG to ground fault, for example). Consider the system shown in Figure 12. If breaker B is open, then the zero sequence current seen by the phase A ground distance function will be fed from a single source and it will be equal to the positive and negative sequence currents flowing down the line. On the other hand, with breaker B closed, the zero sequence current seen by the function can be quite large, especially if the zero sequence source behind breaker B is very strong. The effect of the strength of the zero sequence current and the relay

reach can be seen by examining the operating quantity, **Vop** as shown in Figure 13, for the phase A distance function set with a reach of ZR.

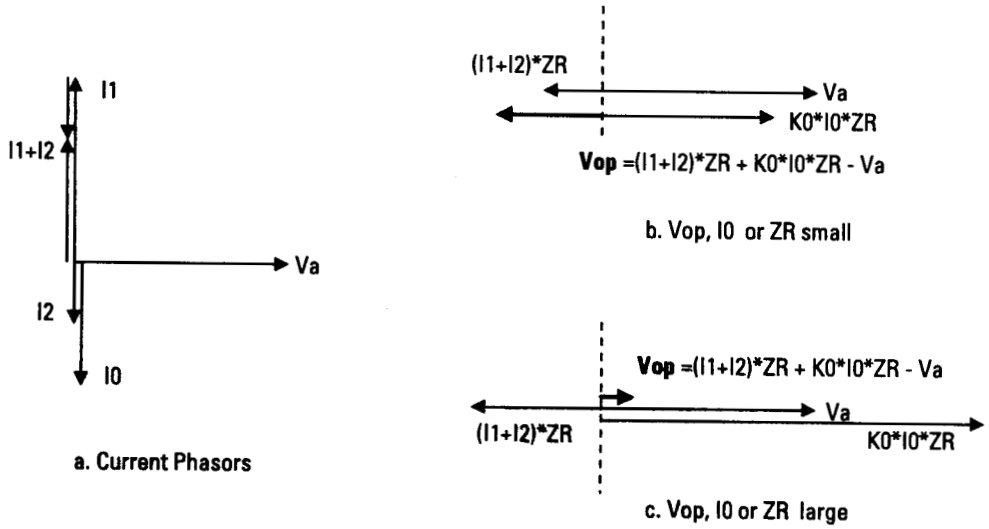


Figure 13 - Sequence Current and Vop Phasor Diagrams for Reverse BCG Fault

The phase relationship of the sequence currents as seen by the relay are shown in Figure 13a (all impedance angles were assumed to be 90° for simplicity). Note that the relay currents are 180° out of phase with those seen by the power system because the fault is behind the relay and the current transformers, when connected properly, will cause this apparent shift. The corresponding Vop operating phasors are shown in Figures 13b and 13c for small I0 and small ZR and large I0 and large ZR, respectively. The polarizing quantity for this function could be the Va voltage itself or it would be a cross-polarized voltage which would be in phase with the Va voltage. The conditions shown in Figure 13a therefore represent a non-operating condition because Vop and the polarizing voltage are 180° out of phase. As the zero sequence current and/or reach is increased the point will be reached where the Vop signal will reverse as shown in Figure 13c. This now represents an operating condition because Vop and the polarizing signal are now in phase.

In general, operation for this condition is minimal on two-terminal line applications unless extremely long reaches are used. The possibility Is increased significantly on three-terminal line applications because of the infeed from the third terminal and also because long reaches are often used because of the effect of infeed. Ground distance functions have been designed and are available to preclude operation for this condition. Each application should be checked for the possibility of operating for this condition.

ZONE 1 GROUNDOVERREACH FOR REMOTE DOUBLE-TO-LINE-TO-GROUND FAULT

It was just shown that the ground function associated with the faulted phase could operate for an L-L-G fault directly behind the function. Another problem can occur for the same fault for a zone 1 ground distance function located at the other end of the line (terminal A). In this case it is possible for the zone 1 function associated with the leading phase[5] to overreach for a resistive fault with

heavy load flowing away from the relay location (refer to reference 5 for details). Operation can be prevented for this condition through design of the function or by limiting the reach of the function. Refer to the instruction book for a specific function to see if it is designed to preclude operation without reach limitations under these conditions or if the reach must be limited to preclude operation.

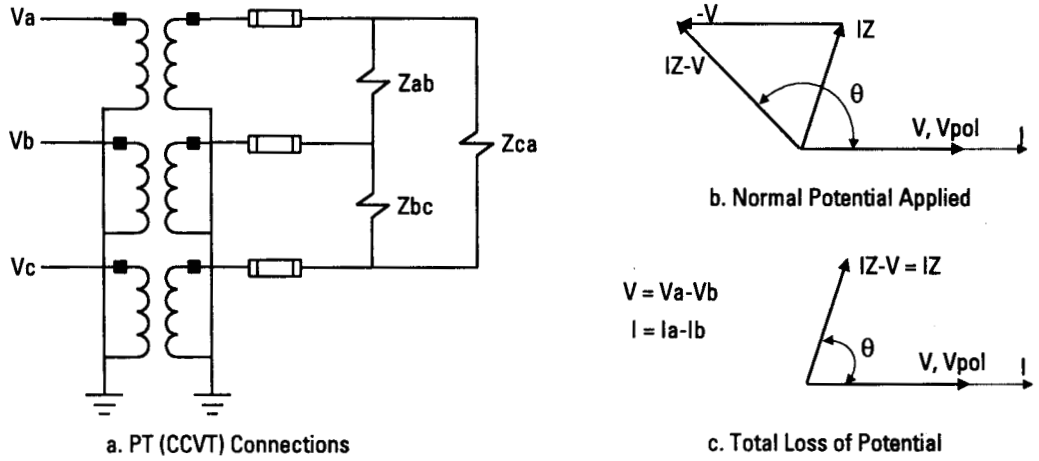
LOSS OF POTENTIAL

Distance functions may operate during when potential is lost, but the following factors must be considered to determine what the overall effect will be:

1. The design of the function and the settings placed on it (reach, angle, etc.)
2. The magnitude and direction of load flow
3. The nature of the potential loss (full or partial)
4. The potential transformer (CVT or CCVT) connections and the total connected burden.

To determine the effects of the above factors, each type of distance function must be examined separately. A phasor analysis will be provided for a self-polarized and a positive sequence polarized phase mho distance function that uses the operating principles shown in Figure 1. For this function, operation will occur when the operating quantity (Vop = IZ-V) and the polarizing quantity (Vpol) are within 90° of each other.

The phase AB function will be analyzed and unity power factor will be assumed (lagging power factor will exacerbate the problem whereas leading power factor will be less onerous). The potential connections to the function and the phasor diagrams for a total loss of potential are shown in Figure 14. For this case, the angle θ is greater than 90° with normal potential applied, but is less than 90° after the loss of potential when Vop is equal to IZ and the polarizing voltage is the memorized voltage V. The function will therefore produce an output, and the output will last as long as the memory lasts. Unfortunately, this is generally long enough to cause a trip, especially in the case of a zone 1 function, or an overreaching function in a blocking or hybrid type of relaying scheme. Although a



a. PT (CCVT) Connections

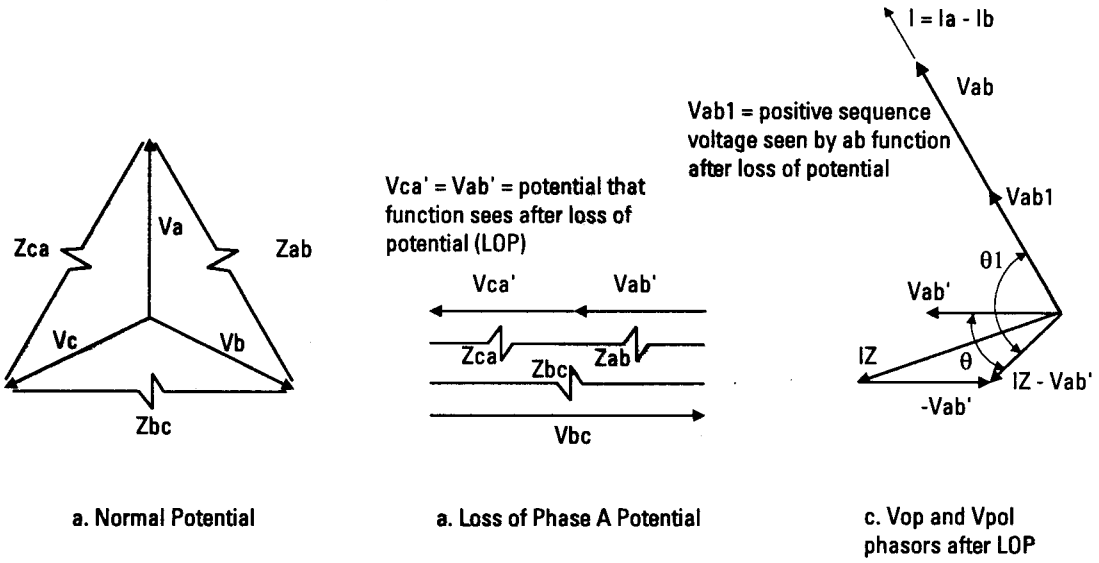
b. Normal Potential Applied

c. Total Loss of Potential

Figure 14 - Potential Connection And Phasor Diagrams for Total Loss of Potential

self-polarized function was analyzed for this example, an output will occur for the case of a total loss of potential for any phase distance function regardless of the type of polarization that is used.

The analysis for a partial loss of potential (phase A fuse blows) is shown in Figure 15. In this case, the self-polarized function will not operate dynamically, but it will operate steady-state as shown



a. Normal Potential

a. Loss of Phase A Potential

c. Vop and Vpol phasors after LOP

Figure 15 - Potential Diagram and Phasor Diagram for Partial Loss of Potential

because the angle θ between Vop (IZ - Vab') and Vpol (Vab') is less than 90°. The positive sequence polarized function will not operate dynamically nor will it operate steady-state (angle θ1 is greater than 90°) because the polarizing voltage Vab1 does not shift in phase although it is reduced in magnitude. Thus the positive sequence polarized function is much more secure than is the self-polarized function.

A similar type of analysis to that used above can be used to analyze the performance of any type of distance function as the result of a loss of potential.

REACTANCE FUNCTIONS

A simple reactance function is shown in Figure 16. Also shown in this Figure is a so-called quadrilateral function which is in reality a form of reactance function. In each case, some form of supervision is required because a reactance function is inherently non-directional. Reactance type functions are often selected because of the apparent increase in resistance coverage over the traditional zone 1 function (shown dashed in the Figure). It should be remembered, however, that a crosspolarized mho function will offer resistance coverage greater than that shown because of its variable nature. Reactance type functions are susceptible to overreaching for faults with resistance in them unless the function is designed to preclude this type of operation. In addition, some quadrilateral functions may not operate for a resistive fault right at the relay location. To demonstrate the overreach problem and one way to overcome it, refer to Figure 17.
Figure 17a shows a self-polarized phase A ground reactance function using the phase A current to derive the polarizing quantity. As can be seen, the effect of arc resistance and load flow (away from

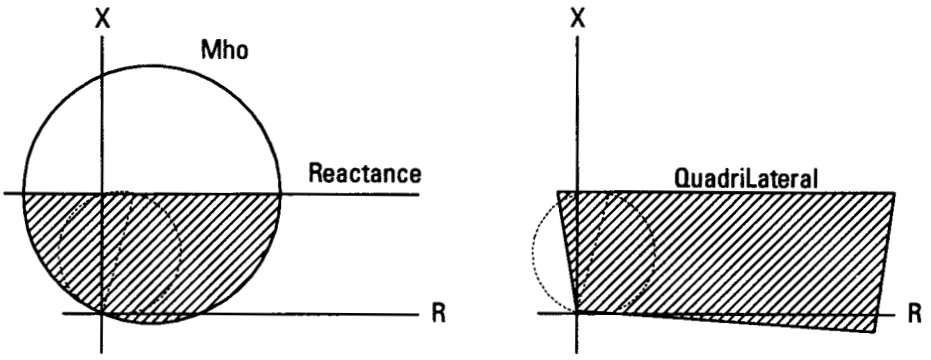


Figure 16 - Reactance Type Functions

the relay in this example) has caused the function to overreach ($\theta < 90°$). For load flow in the other direction, this self-polarized function will have a tendency to underreach. The negative sequence polarized function shown in Figure 17b does not overreach for the same condition as does the self-polarized function, nor will it underreach for load flow in the other direction. Other polarizing sources, 3I0 for example, may be used for polarizing to prevent overreaching. Further details on the performance or reactance type functions can be found in reference 1.

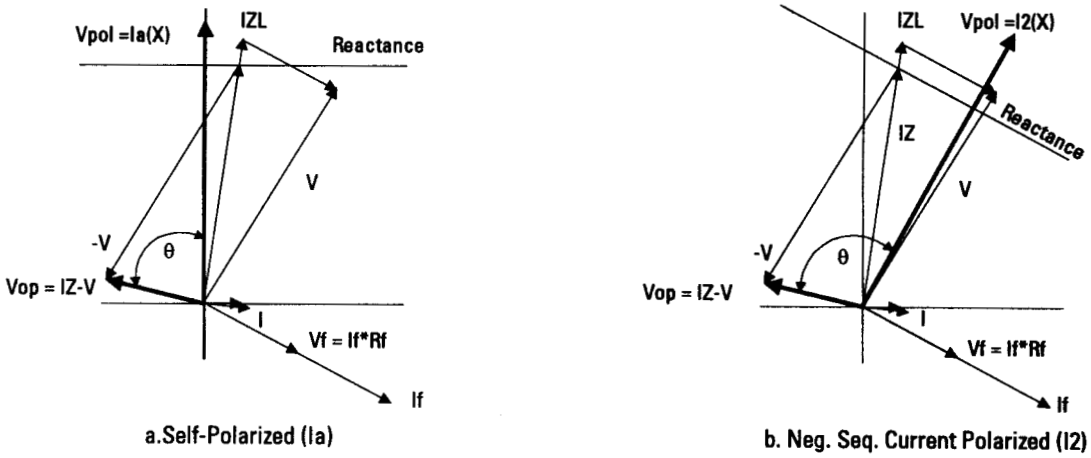


Figure 17 - Self-Polarized and Negative Sequence Current Polarized Reactance Functions

COUPLING CAPACITOR VOLTAGE TRANSFORMER (CCVT) TRANSIENTS

Coupling capacitor voltage transformers are an economical way to obtain the potential required to operate distance (and directional) type relays. They also provide a means to couple communication channels to the power line for use with various relaying schemes. Unfortunately, a CCVT may not reproduce the primary voltage exactly and can introduce significant error into the distance relay measurement The transient error that is produced by the CCVT becomes more pronounced as the change in the voltage from prefault to fault is increased (a fault at the end of a line with a high source to line impedance (ZS/ZL) impedance ratio, for example). A typical CCVT transient is shown in Figure 18. If a transient like this were to occur for a fault at the end of a line with a high ZS/ZL ratio, it could cause a zone 1 distance function to overreach. To see how this could occur, refer to Figure 19.

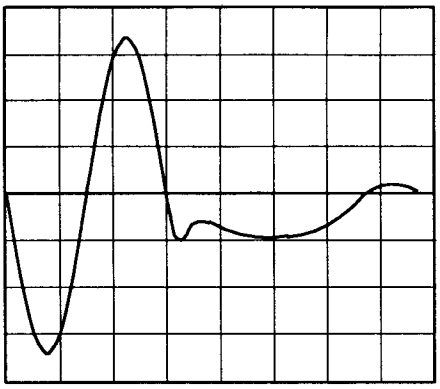


Figure 18 - Typical CVT Transient

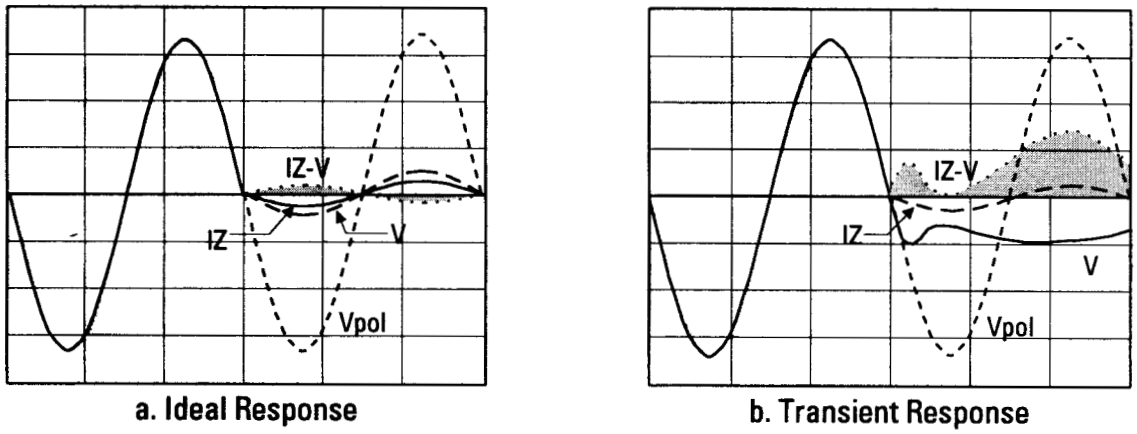


Figure 19 - Distance Function Operation for Ideal and Transient CVT Response

The operation is shown for the distance function and system of Figure 1 with the assumption that the source to line impedance ratio (ZS/Z) is approximately 15. The ideal response shows that the function will not operate because the operating quantity, IZ-V, and the polarizing quantity, Vpol, are 180° out of phase. The transient response on the other hand shows that the function will operate during the second half cycle because the operating quantity and the polarizing quantity are in phase with each other (see shaded area). This example shows that care should be taken in the application of zone 1 distance functions and that the recommendation of the manufacturer should be followed in making the reach settings on the functions.

CCVT transients may also cause loss of directionality for zero voltage bus faults behind the relay. The use of memory voltage and cross-polarization will reduce this tendency.

CONCLUSIONS

Distance functions perform a very important and essential part of many power system protective relaying systems. This paper discussed possible problem areas that can be encountered in the design and application of distance type function. It is the responsibility of the manufacturer to design relays, and to aid in their application, with these problems in mind. However, it is the ultimate responsibility of the user to insure that the relays are applied correctly.

References:

1. Polarization of Ground Distance Relays, W.Z. Tyska

2. Dynamic characteristics of Mho Distance Relays, GE Publication GER-3742

3. Art & Science of Protective Relaying, C. Russell Mason, John Wiley & Sons, Inc.

4. Protective Relaying, J. Lewis Blackburn, Marcel Dekker, Inc.

5. Effects of Load Flow on Relay Performance, General Electric Publication GER-3743

6. Ground Distance Relalying: Problems and Principles, General Electric Publication GER-3793